LUBRICATION

A Technical Publication Devoted to the Selection and Use of Lubricants

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The Lubrication of Sugar Mill Machinery

THE proper lubrication of sugar mill machinery and equipment is one of the most interesting parts of the work of a lubricating engineer. The importance of keeping this machinery in first class running condition is a paramount one, especially at the present time when so many new plants are being erected and old ones and those formerly using windmills for power, are being equipped with modern machinery for the manufacture of a product which is so much in demand, and which is now occupying one of the most prominent positions in world commerce. As very few persons not in direct contact with the work, and among them lubricating salesmen, know very little, if anything, of the cultivation of sugar cane and its manufacture into sugar, it will no doubt, be of interest to give a short description of cane growing and the process through which it is made into sugar. I shall take them into the life of which sugar making is the center, that they may get in touch with its stern realities and feel the fascination of its subtle romance.

As the West Indies and parts of South America are the nearest localities producing sugar outside of the United States, let us take these as our field. The first step in sugar making is the cultivation of the canes, second the transportation of them to the mill and third the crushing of the cane in the mill to extract the juice. In Cuba and Porto Rico the making of sugar has been so Americanized that the romance of old plantation life has practically disappeared, but in Dutch and British Guiana, and Brazil in South America, Trinidad, Barbados, St. Kitts and Jamaica, British West Indies, and in Martinique and Guadaloupe, French West Indies, the fascination and romance of this great industry is the same as it was more than a hundred years ago.

Sugar is developed from materials which exist in the sap of certain plants. The chief sources of the world's sugar supply are the sugar-cane and the sugar beet, and these two plant families are the prime givers of the millions of tons of sugar which are yearly distributed north, south, east and west, to be consumed in connection with some food or drink by you and me, our friends and our neighbors, and the vast majority of the inhabitants of every quarter of the globe. Among other plants which are minor producers are the sugar-palm tree of India, the sugar maple tree of North America, and an African corn plant called sorghum, which has been introduced into the United States, but none of these sugars is in a position to compete with cane sugar or beet

sugar, which together rule the world's sugar market, although beet sugar production has greatly decreased on account of the World War. The sugar cane family is generally believed to be of Eastern origin, although some old writers say that the West Indies and Central America have an equal claim to be its native land, but most authorities agree that Cochin China is its real homeland, whence it was introduced into China, India and Arabia, and during their world-famous period of political supremacy the Arabs started the cultivation of sugar cane in all parts of the widespread Mohammedan Empire including Spain. The Spaniards then transported it to the West Indies and Mexico, and taught the natives the art of sugar making.

THE CANES

Each cane is composed of root, stalk, leaves and some species have a head of flowers. The stalk, which contains the sugar juice, is ringed with joints at from about 2 to 6 inch intervals throughout its whole length of from 8 to 12 and sometimes 20 feet; each joint contains a bud, which is the germ of a new cane. Luxurious, bladelike leaves spring out at every joint of the stalk, the topmost leaves clustering into a thick bunch. As the cane ripens, out of the sheath aloft shoots an arrow, long and slender and richly adorned with white or grey feathery heads of countless little silken flowers. Broadly speaking, the system of sugar cane cultivation is the same in all parts of the sugar world, and every cane crop not only gives a sugar harvest but supplies a stock of cutting for the next season's crop. After the harvest the ground is plowed or hand-forked, and either furrowed or drilled in rows, from 3 to 6 feet apart; plant canes or cuttings from the tops of ripe canes are then laid horizontally in the furrows or holes, or thrust in at an angle, a foot or two apart, and lightly covered with earth. The eyes of the joints soon begin to spring, and the young canes enter on the life of about 16 months, which they require to reach a state of perfection; the roots split up and spread in all directions.

There is another important operation that must be performed between harvests. The full-grown leaves of a sugar cane field make up a tangle of exuberant, tropical vegetation; a few of them drop off as the canes ripen, but the great majority cling fast to the stalks and rival the undergrowth of a tropical forest. This "trash" is usually cut away by hand, but is sometimes removed by fire, and when the "trash" is being burned away you will find it difficult to realize that you are not witnessing a terrible catastrophe. Ferocious flames lick through the whole field and dart up to the sky, amidst awesome clouds of dense smoke, and it looks as though the whole field would be devoured, and that the neighboring fields must surely be devastated. The marvelous fact remains, however, that the flames devour the trash without destroying the canes; some planters claim that it does not harm the sugar juice, while others are certain that the scorching heat is very harmful and remove the trash by hand.

After trash clearing comes the harvest. The canes are reaped by hand with different kinds of knives in different parts of the world; they are severed close to the ground and any leaves remaining are cut off, and a short piece is slashed off from the top which is kept for planting. The stalks are taken to the mills to be crushed, some being hauled by locomotives and trains, some by mule and donkey carts, and some in punts drawn by mules through canals, the latter method being in operation in Dutch and British Guiana where canals traverse all parts of the fields. The leaves of the canes are used for fodder.

MAKING THE CANE SUGAR

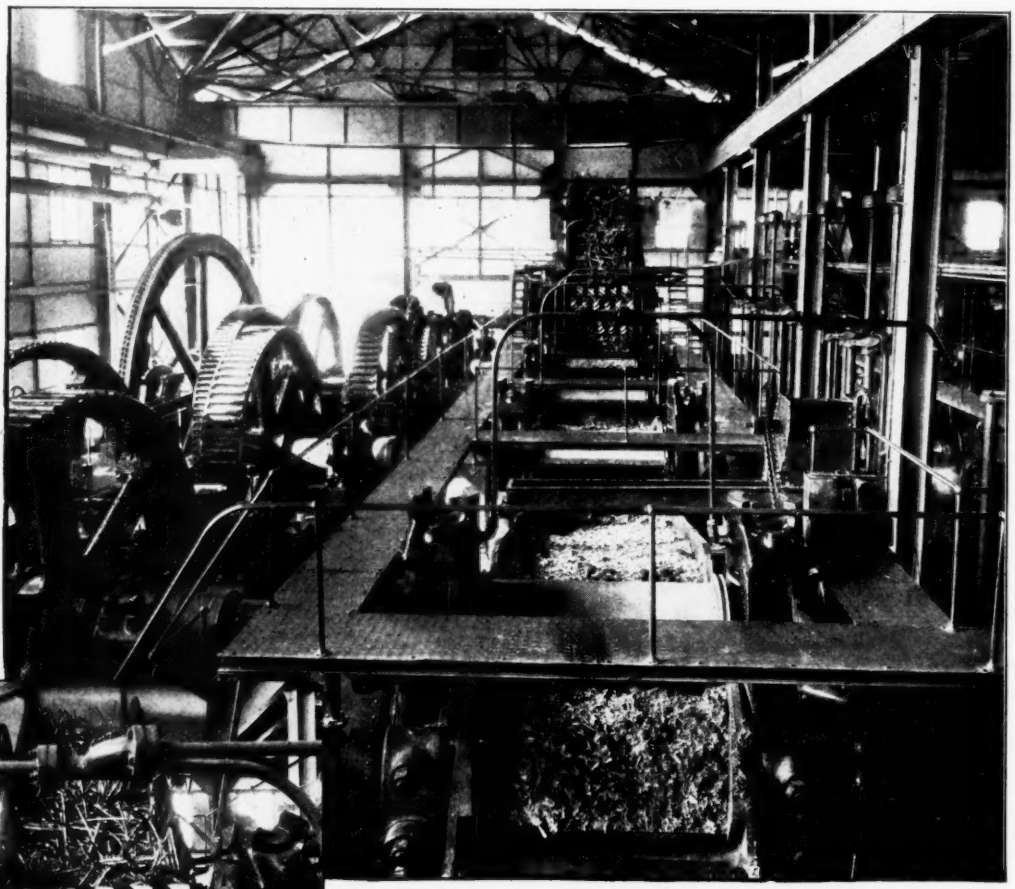
The first step in sugar making is to extract the juice from the cane and beet. For this purpose the canes are placed on carriers operated by machinery and carried to the great crushers or rollers of the mill, designed to squeeze out practically every drop of juice. The juice extracted by each set of rollers passes through copper strainers and is conducted through channels and pipes into one large collecting tank. Another carrier takes away the crushed remains of the canes, called magasse and bagasse, which furnishes a large portion of the fuel used in sugar mills. The cane juice is then pumped from the large collecting tank into various

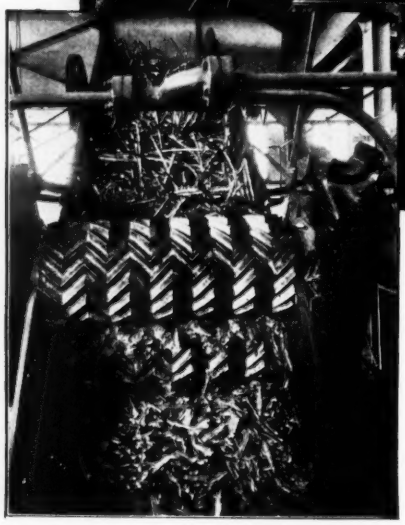
smaller ones and mixed with a certain quantity of lime for neutralizing the acid and clarification purposes; it is then pumped through steam heated vessels and raised to boiling point or higher. It is then pumped into other tanks, where it is allowed to settle for a short time so that the impurities will sink to the bottom; when this is done the clear juice is conducted to a series of evaporators called Triple and Quadruple Effects, to be there concentrated until it attains the consistency of a thick syrup. The action of a triple effect is to cause the concentration of the cane juice at a low temperature. The process is carried on in a series of large vacuum pans so arranged that the vapors arising from the liquor boiling under a vacuum of 5 to 7 inches in the first pan, serves to heat and boil the contents of the second pan working under a vacuum of 15 to 17 inches. The third pan of the series working under a maximum vacuum of 25 to 27 inches in like manner utilizes the vapors from the second pan to heat and evaporate the liquor transferred into it. The three pans as described are called the triple effect. The syrup formed is then drawn into vacuum pans and evaporated until crystals form. While the crystals are incubating, constant tests are made of the boiling syrup by an employee called a "Pan Boiler," whose position is most important. To note the gradual growth of the crystals he exposes a small quantity of the boiling syrup on an ordinary piece of glass and there is a look of great anxiety in his eyes as he closely examines the specimen substance of the pan, for a trifle too little or a trifle too much boiling will spoil the contents of the pan. Moreover, his reputation, very likely an excellent one of long standing, will suffer if he makes a mistake.

When the crystals are sufficiently formed, the contents of the pan are discharged into a tank below; the substance at this stage is known as "masse-cuite," and consists of crystals mixed up with a syrupy residue called molasses. The compound is a sticky, dark-colored mass which does not bear the slightest resemblance to golden sugar-crystals, yet in a few seconds, by a simple operation, it is transformed into a familiar aspect. All that remains to be done is to separate the crystals from the molasses, and for this purpose the "masse-cuite" is discharged into centrifugals, wonderful machines, circular in form that have a network lining of very fine mesh. Herein it is whirled around at the lightning speed of about 1200 revolutions per minute, with the result that the liquid part of the mass is forced through the meshes, and the crystals are left high and dry. In a golden shower the crystals tumble out into a conveyor, which runs them up to the storage bins, ready for packing and shipping. The sugar leaves the storage bins via a chute to the ground floor; a weighing machine stands beneath its lower mouth which can be opened or shut as desired by a slide. Empty bags take their turn on the weighing machine, and as each one gets its fill of 250 pounds, or 8 bags to a ton of 2,000 pounds, it is removed and securely fastened. In Cuba a bag of sugar weighs 320 pounds, or 7 bags to the long ton of 2,240 pounds. With little or no delay the bulging sugar bags are sent to the port of embarkation, where they are loaded in cargo ships bound for the markets of the world.

BEET-ROOT SUGAR

To make sugar from sugar beets the beet roots are shredded and their juice is extracted by a process technically known as "diffusion." Simply explained, this is what happens: hot water is let into a closed vessel which contains a mass of beet-root shreds, and as a natural consequence the beet-root juice begins to escape from the plant cells to mix with the water, while the water begins to penetrate the cells to mix with their juice. This intercourse goes on until the liquid within the beet-shreds and that in which they are immersed are of equal density, by which time what was originally water is now syrup. This syrup is conducted to a second vessel containing beet shreds, and the same natural mixing again takes place, the immersion liquid being fortified with a further supply of sugar juice; this process is repeated until diffusion practically ceases as the immersion liquid has become as dense and as good in quality as the natural juice of the beet, and neither wants to mingle with the other. In other words, the hot water put into the first vessel has become saturated with beet juice.





1—Cutting cane by hand.

2—Car on tilting platform dumping cane into cane pit. Cane carrier conveying it from pit to mill.

3—Cane being crushed. Entering at top of mill, running through crushers and rollers and emerging as bagasse.

3a—Closeup of cane going through crushers.

Photographs, courtesy of Honolulu Iron Works and Reading Iron Company

The diffusion is then drawn off, and at this stage corresponds with the cane juice extracted by crushing. The refuse of the beet is called pulp and is dried and used for cattle food.

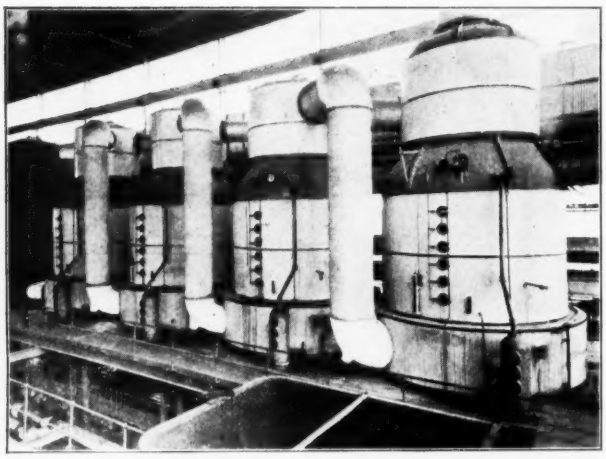
The color of sugar is determined by its degree of purity, pure sugar being white, or strictly speaking, colorless. The sugars made at cane mills and beet mills are, as a rule, gray, brown, or some shade of yellow from pale lemon to bright gold. Those of yellow hue have been sufficiently clarified to be sold for household use; the grays and most of the browns go on to a refinery, where they are melted and subjected to a more rigorous purification. Water plays a very active part in the bleaching and refining of sugar; so does the "blueing" which your washerwoman uses. "Which is the better sugar," you are wondering, cane or beet? An expert in each sugar says that cane sugar and beet sugar are equally good; the impurities of cane juice have a pleasant taste and smell, while those of the beet juice are unpleasant, but when the sugars have been refined not one person in a million can tell which is which. But an old housewife says that preserves keep better when made with cane sugar.

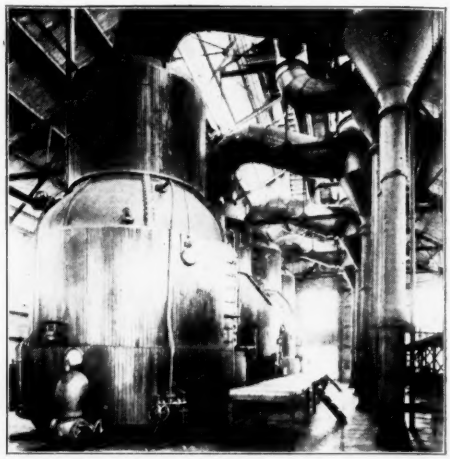
Sugar estates in this part of the world range from two or three thousand acres with 800 to 900 employees, to over a hundred thousand acres, with thousands of men, women and children employees. The estates in Antigua, St. Kitts, Barbados and Jamaica, Cuba and the French West Indies depend almost entirely upon negro labor, which is getting worse and worse as the years go by, and in Trinidad and British Guiana the labor is mostly East Indian coolies, indentured for five years, who still wear the costumes of their native land and follow the Buddhist religion. In Dutch Guiana the estate labor is Javanese from the Island of Java.

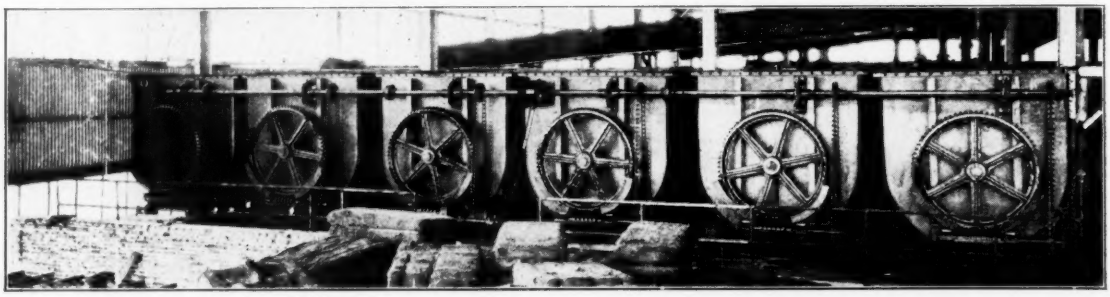
SUGAR MILL MACHINERY

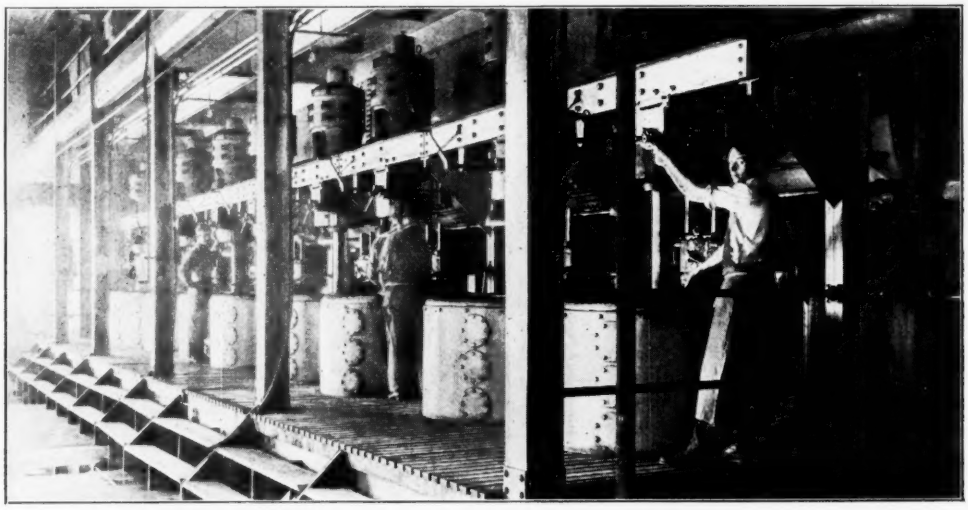
The different kinds of machinery required to operate a sugar mill, the enormous size and weight of some of the parts, and the different speeds at which the machines run, is a revelation to the inexperienced lubricating engineer in this line of industry. Let us take for example an average size sugar mill of 11 rolls. This means that there are three sets of rolls of three rollers each and two rolls for use as crushers or breakers of the cane as it comes from the carriers. All the sets of rolls are in tandem; in some mills instead of two rolls as preliminary crushers two sets of revolving knives are used to cut the canes up into small pieces before it is passed on to the mill rolls, and others use large machines called shredders. The mill rolls, crushers and cane carriers are driven by an immense main steam engine, having a cylinder 30 inches in diameter by a 60-inch stroke, working at 100 pounds steam pressure per square inch, and from 45 to 70 revolutions per minute, whose power is transmitted through a great "spur" wheel or main gear wheel of about 9 feet in diameter, with a face 11 inches wide on which the teeth, about 2½ inches thick, are cast. The main gear wheel weighs from 4 to 8 tons, and the teeth on its face mesh with the teeth on smaller gears and pinions, carrying the power to the mill rolls, crushers, and cane carriers. The fly wheel of the main engine ranges from 12 to 20 feet in diameter and weighs, in some cases, as high as 26 tons. The cylinders of other main engines in larger mills run up to 36 inches in diameter by an 84-inch stroke; other mills are operated electrically, especially in Cuba where the largest sugar mills in the world are located. Other steam engines required in sugar mills are vacuum pumps, engines for the triples, engines for the centrifugals, fan engines, etc., and many pumps including rotary pumps, centrifugal pumps, irrigation pumps, turbine pumps for driving centrifugals, etc., all of which require expert lubrication. Then come the sugar centrifugals ranging in number from four to twenty and more, according to the capacity of the mill, which also require expert lubrication; they run from 30 inches to 54 inches in diameter, and have an average speed of 1200 revolutions per minute. Some use oil and some grease lubrication.

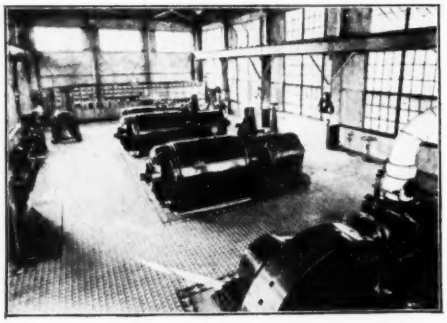
The big mill rolls and crushers range in size from about 20 inches in diameter by 36 inches long, to 40 inches in diameter by 80 inches long, with journals from 12 to 22 inches in diameter. These journals are the most difficult parts of sugar mill machinery to lubricate successfully on account of the immense pressure required











1—Quadruple effect.
2—Vacuum Pan.
3—Crystallizers.
4—Battery of Centrifugals.
5—Electric Plant in a large Sugar Central.

Photographs, courtesy of Honolulu Iron Works and the Cresson-Morris Company

to extract the juice from the cane. The hydraulic pressure on the top rollers range from 200 tons in the smaller mills to 650 tons in the largest mills, and the heating up of these journals much above normal running temperature means serious trouble, if not a shut-down of the mill for repairs, which entails a heavy loss in the production of sugar.

A great many sugar estates have quite a railroad system to handle the canes from the fields to the mill, and have a number of locomotives and cars for this purpose, all requiring expert lubrication. The tractor for plowing the fields is now coming into general use on account of a shortage of labor. These machines also are large consumers of lubricants. Sugar estates having no railroads to transport the canes from field to mill use a large number of carts, all of which use considerable axle grease. All sugar mills provide their own electric lights and have dynamos of various capacity which also require lubrication. There are also cane hoists, small machine shops and other small machinery connected with sugar estates that require lubrication.

The above is, generally speaking, the essential machinery required in sugar mills for the manufacture of sugar, the lubrication of which requires constant study and attention on the part of the lubricating engineer. Sugar mills, generally, have an experienced mechanical engineer as chief engineer of the plant, who is well up in lubrication and knows what he wants, but is always open to suggestions from experienced lubrication engineers. His responsibilities are heavy, as, generally he has poor material from which to select his engine operators, who always require his constant supervision.

The capacity of sugar mills vary, ranging from 300 tons to 100,000 tons of sugar per season according to size. The grinding season extends from about December 15th to August 1st according to location. During the intervening months the many repairs required on the machinery are attended to by the mechanical staff, while the agricultural staff looks after the planting of new cane and attending to the growing canes for the next season. The working time of sugar mills is from 15 to 24 hours per day, an average size mill grinding about 40 tons of cane per hour, and producing up to 600 or 700 tons of sugar per week of six days, no work being done on Sundays. Some mills, having a large staff, work night and day.

From the foregoing description of the machinery and equipment in a sugar mill it is seen that the engineer in charge must carry quite a number of lubricants in order to satisfactorily meet all the conditions. On account of the distance from the market and the poor quality of labor usually obtainable, it is advisable to make the number of lubricants as small as possible, and also to purchase them from one firm if at all practical. We shall indicate below in a general way how the machines can be lubricated to get the best all-around results, taking into consideration the conditions.

The steam cylinders of sugar mill engines, steam tractors, locomotives, etc., should be lubricated with a high grade cylinder oil of about 130 seconds Saybolt viscosity at 210° F. If the main engines are condensing or use superheated steam a straight mineral cylinder oil can be used in this case but for ordinary auxiliary engines compounded oil is preferable if not almost essential. If it is desired to carry only one cylinder oil, one with a light compound is recommended as meeting all the conditions most satisfactorily. If two cylinder oils are carried, as they look alike they are sure to get mixed unless great care is taken, and the object of carrying two oils is defeated.

For the lubrication of internal combustion engines on tractors it is advisable to carry an oil of 500 to 750 viscosity, especially designed for tractors. Of course, any oil of above viscosity can be used and may give fair results if the cylinders are cleaned frequently, but a special non-carbonizing oil is preferable. For the lubrication of bearings, guides, links, eccentrics, etc., of sugar mill engines a straight run oil of 300 to 500 viscosity will give satisfaction, the heavier, larger engines naturally requiring the higher viscosity oil. For light engines, dynamos, etc., an oil of 200 to 300 seconds viscosity should be used. For centrifugals, on account of their high speed and exact construction, a fully refined, filtered oil is to be preferred. Usually an oil of 200 seconds viscosity will operate most satisfactorily. For unusually

large units it may be preferable to use 300 seconds oil or for very small units an oil with less viscosity than 200 seconds may give slightly less running friction but almost universally the 200 seconds oil will be the most practical to adopt.

For the lubrication of the heavy mill roll, crusher and gear bearings, on account of the high pressures, a heavy bodied lubricant is necessary. Ordinary oils have not sufficient viscosity to keep the surfaces apart on account of the comparatively slow speed and heavy pressures. A lubricant of about 200 viscosity at 210° F. seems to meet the requirements and a straight petroleum product seems to give better results than a grease or compound. This type of lubricant also has the advantage of adhering tenaciously to the bearing and of not being worked out by the variation of pressure to which the roll bearings are subjected. It also has a most important advantage of being comparatively cheap, which on account of the size and number of large bearings, is not an inconsiderable factor. A similar type of compound, but of a viscosity of about 1000 seconds at 210° F. is most suitable for gears. This compound should be very adhesive to metal and of such a consistency that it will not run, drip, or crumble from the gears, and still be sufficiently plastic to furnish good lubrication. This same compound should be used on wire ropes, chains, hoists, conveyors and outside exposed surfaces.

Where turbines are used the oil used must be particularly refined so as not to emulsify with water. In most turbines, continuous systems of oiling are used and as the oil generally comes in contact with steam, and its mixing with water can hardly be prevented, the oil must separate quickly from water and not form a foam or emulsion. If the oil is not used in a closed system this special refinement, of course, is not absolutely necessary, unless there is a chance of the oil and water mixing in the bearing. The viscosity of the oil necessary for turbines varies according to size and type, ranging from 180 seconds to 300 seconds, though 180 seconds is generally most satisfactory.

For the lubrication of the moving parts of locomotive machinery, such as eccentrics, links, guides, etc., a locomotive engine oil of from 400 to 450 seconds viscosity at 100° F. should be used. For the lubrication of cane cars a summer black oil meets the needs. Throughout the plant there are many places where grease is necessary. Probably two grades will satisfy all the conditions, No. 3 and No. 5, except if there are wagons, axle grease is much cheaper.

In the foregoing we have covered in general the lubrication of the principal pieces of machinery in a sugar mill. There may be a number of machines not covered but with the lubricants recommended almost any machine can be satisfactorily lubricated. To recapitulate, we have specified the following types of oils:

1. Cylinder oil, slightly compounded.
2. Roller lubricant.
3. Heavy engine oil.
4. Light engine oil.
5. Light engine oil for centrifugals.
6. Gear compound.
7. Turbine oil.
8. Two grades of grease.
9. Locomotive engine oil.
10. Internal combustion engine oil.

These grades will cover almost any case and are sufficiently overlapping that in case one grade becomes exhausted there is another that can be used, though not necessarily as satisfactorily. The list can be expanded or contracted according to conditions.

While we have covered the subject in a general way and have indicated proper lubricants for various types of machines, these machines vary to such a degree that no fixed rule can be laid down. The lubricants recommended will prove satisfactory in the majority of cases, but it is strongly advised that the engineer shall not content himself with them entirely but at the first opportunity that he quiz the lubrication engineer of some reputable company which has had experience in his line, and get the benefit of its broad information.

Saponification, Emulsification and Adhesion

IN THE endeavor to meet the increasing demand for lubricants that will operate under particular conditions, the lubricating engineer is continually compelled to develop lubricants which require especial treatment, compounding or refining, in order to produce the properties necessary for satisfactory operation. This is illustrated in the development of lubricants which will function efficiently in the presence of moisture or wet steam. Straight mineral oils under some water conditions are far from satisfactory but can be greatly improved or even made entirely efficient by compounding with certain fatty oils or their derivatives. Both in studying this action of oil in the presence of water and that of an oil which will easily separate from water, we meet the terms saponification, emulsion and adhesion. These terms have been used so loosely by some engineers and writers that apparently a confused impression seems to exist as to their real significance, or what is more important, as to the relationship which exists between them. While the problem as to the action of the underlying physical and chemical forces producing the effects indicated by these terms has not as yet been completely solved, yet enough experimental data has been accumulated, and scientific opinion has been sufficiently crystallized as to give a fairly definite meaning to them. We shall endeavor to explain these terms as generally understood in the oil trade.

SAPONIFICATION

Saponification is a chemical action pure and simple, and should not be confused with any physical effects which may result therefrom. Certain organic compounds, on account of a great similarity in chemical properties and possessing certain particular physical characteristics, are grouped together and called oils. Based on origin, composition and chemical behavior these in turn are subdivided into two general classes called mineral oils and fatty oils. One of the principal characteristics possessed generally by fatty oils and not by mineral oils is their susceptibility to a simple chemical reaction whereby the oils are split up and re-combine with metals, generally those belonging to the alkali group. These combinations of the major portion of the oil molecule with a metal in this manner are called soaps and the chemical reaction is called saponification. The most common soaps are produced by the treatment of a fat or fatty oil with caustic soda or potash, but soaps containing calcium (lime), aluminum, and lead are often encountered in the oil trade. Although soaps are usually produced direct from the oils or fats, the same result is obtained by the action of an alkali upon a fatty acid and the term saponification may even be used for the action of an alkali upon those acids of an organic nature found or produced in a slight degree in mineral oil or petroleum products. Except as noted in the last sentence, petroleum oils will not saponify.

This property of fatty oils to easily produce soaps is used as a means of determining the presence of such an oil and approximately its amount in a mixture of mineral and fatty oils. Most fatty oils will react with caustic soda or potash to approximately the same degree, that is, equal amount of fatty oils will neutralize the alkalinity of about the same amount of caustic. In order to be able to express this effect in figures, the number of milligrams of caustic potash that will react with or be neutralized by one gram of oil is called its saponification number. The saponification numbers of most fatty oils range between 190 and 200. By finding the saponification number of an unknown oil a fair approximation can be made as to the amount of fatty oil it contains. If the nature of the fatty oil is indicated by other tests the percentage can be determined more exactly, as the saponification numbers of pure oils are known.

EMULSIFICATION

If a well-refined mineral oil and water are shaken up together in a bottle and then allowed to settle for a few seconds, both liquids separate with a sharp surface of demarcation and are clear. If, however, certain fatty oils or soaps are added to the mineral oil and the bottle shaken again, the two liquids will separate only very slowly or may even remain mixed practically indefinitely. This intimate mixture of oil or oil compound and water is called an emulsion. The term as used in the oil trade therefore may be defined as a very intimate mixture of two liquids which are insoluble or only slightly soluble in each other, which

mixture is so stable and the liquids are so mutually held in suspension that separation due to differences in specific gravity or density is very slow.

This definition, while covering the usual conception of the oil trade is somewhat broader than sometimes given in scientific discussion. As can readily be seen there are practically no limiting conditions which will definitely determine whether we have an emulsion or not, as the transition from a solution to an emulsion is not sharp and it is easily conceivable that we may have an emulsion and yet the combination of two liquids appear clear and apparently a true solution. On the other hand, the two liquids emulsified may have such a mutual action on each other that the combination may apparently be a solid. This has led some scientists to divide what we have classified as emulsions into two groups, suspensoids and emulsoids. Suspensoids include roughly the cases where one liquid is suspended in another and yet the combination has practically the same viscosity and other physical characteristics as the suspending liquid or, as generally called, the dispersion medium. Where the suspended liquid or disperse phase changes the characteristics of the dispersion medium to a marked degree the combination is known as an emulsoid. This change of characteristics is well illustrated by the action of a soluble oil and water. Water will suspend a considerable quantity of soluble oil without appreciably changing its viscosity. There is a point, however, when the addition of oil to the combination starts to increase the apparent viscosity very rapidly until with certain proportions of oil and water the combination when thoroughly mixed has the consistency of a solid. Conversely, water may be added in small quantities to the oil and not change its viscosity to any marked degree but the change is more rapid in this case than when oil is added to water, and the combination reaches the solid consistency with comparatively small quantities of water added to oil.

The study of the causes of emulsification are still very incomplete and there are many characteristics yet to be satisfactorily and completely explained according to the usually accepted theories of physical and chemical science, yet great advance has been made and sufficient experimental data has been accumulated as to allow us to predict results to a fair degree of accuracy. The most generally accepted theory is that there is a balancing of physical and perhaps chemical forces at the surfaces between the two compounds, in this case liquids, so that there is no resulting tendency for the separate drops to coalesce on the one hand or to further subdivide on the other. These forces are sufficient to prevent or at least so retard the action of gravity from separating liquids of different density that they remain in more or less permanent emulsion. Some liquids, as soluble oils, will emulsify spontaneously with great rapidity, the particles reaching their final balanced state of subdivision very quickly, while other liquids must be mechanically or otherwise atomized before they will remain permanently in suspension. In some emulsions the particles are so small that they can only be observed under an ultramicroscope. When thus seen they are found to be in constant rapid motion, the smaller particles being most active. This is called *Brownian movement.* In some cases the particles are so fine that they cannot be seen by the ultramicroscope and are only believed to exist by reason of the fact that a beam of light is scattered in passing through a solution or liquid combination containing these particles. This scattering of a light beam, called *Tyndal effect,* is generally taken as indicating the dividing line between a true, molecular, solution and an emulsion, or colloidal solution.

ADHESION

As in the case of an emulsion of two liquids mutually insoluble or at most only slightly soluble, there are certain interfacial forces operating at the dividing surfaces, so also between a solid and a liquid there are interfacial forces whose action depends upon the composition and physical condition of the two substances. If mercury is brought in contact with glass under ordinary conditions there is apparently no attraction between the two and the glass is not "wetted" by the mercury. There, however, is such an attraction between the two and it has been actually measured in units of force, but this attraction is less than that existing between the different mercury particles and none of the mercury adheres to the glass. If, however, mercury comes in contact with gold and some other metals the attraction between the two metals is greater than the forces between the mercury particles and the gold is wetted by the mercury. This force drawing a liquid to a solid is called adhesion.

If oil comes in contact with glass, the latter is wetted showing that the forces between glass and oil are greater than those between the oil particles. Similarly there is strong adhesion between water and glass. Now if glass is wetted with an oil and then immersed in water, sometimes the water will replace the oil film on the glass and other times the oil will not be dis-

lodged depending on the nature of oil or what may be dissolved in it or the water.

This same action is also true of steel. When wetted with certain oils it will entirely lose its oily coating when subjected to water especially if warm, while other oils will not be displaced and the water will drain off leaving the steel wet with oil.

Some minerals, as certain sulphides, will become coated with oil when treated with an emulsion of particular oils and water, while other minerals will only take on a water coating. This differentiation is one of the principal features underlying the flotation method of concentrating ore. The sulphides will be wet with oil and supported by bubbles formed in the process, can be made to float away from the rock and gangue, which is only wet with water.

It is thus seen that adhesion varies considerably between different liquids and solids, depending upon the composition, nature or impurities in the two substances, or more particularly in the interfacial surface between the two substances.

No general satisfactory method has been devised for measuring the adhesion between a liquid and solid, especially if it is stronger than the cohesion of the liquid, though measurements have been made, where the forces of adhesion are weaker than those of cohesion, that are claimed to show the magnitude of adhesive forces. On account of this lack of actual experimental measurements the study of adhesive forces has been greatly retarded and their explanation has been more a matter of deductive reasoning from assumed hypotheses than is desirable for practical application.

SURFACE TENSION

In attempting to develop a reasonable explanation for adhesion and emulsion on the basis of the usually accepted physical and chemical conceptions we meet another term, namely, surface tension. As mentioned above in discussing emulsions, at the boundary surface between two liquids, not mutually soluble, or between liquid and gas, there apparently exists a different set of forces than are found in the interior of the liquid or gas. If a wire is immersed horizontally just below the surface of a liquid, which wets the wire, and then raised slowly, as the wire is drawn through the surface the liquid follows the wire just as if the surface were a membrane being stretched. The force necessary to pull the wire away from the surface can be measured on a balance, and knowing the length of the wire, this surface force of the so-called liquid membrane can be computed. This force called surface tension differs somewhat from that in a stretched membrane in that it is constant no matter how far the liquid is extended.

It is a fundamental scientific principle that any system possessing potential energy tends to change its form or condition so that this type of energy is decreased. As the energy in a liquid surface is a function of the surface tension and the area of the surface, and as the surface tension is constant, this potential energy will be decreased by a decrease in the surface area. Thus one liquid when surrounded by another liquid or gas, unless prevented by other forces, as those of gravitation, tends to form a sphere which geometrically has the least surface for the volume contained.

The phenomena of surface tension, briefly described above, has been used quite generally and fairly successfully to explain emulsions, though it is apparent that other forces may be co-existent and must be considered, for the surface tension theory does not completely explain all the phenomena. By analogy the theory is advanced that there are forces at the surface of a solid similar to those at the surface of a liquid and there are some experiments which seem to give some credence to the theory, but this force is not measurable and it is not believed that the study has advanced sufficiently to warrant the acceptance of this theory, until further proof is advanced to establish it. Whether there are surface tension forces in the solid or not, still there certainly are forces at the surface between the liquid and solid, as exemplified by adhesion and absorption and we shall still stick to our term adhesion until a better one is established.

In spite of the incompleteness of explanations of interfacial relations still a few general facts stand out and need not be confused with theory:

1. The lower the surface tension between two liquids can be made, generally speaking, the more easily they will emulsify, or slower they will separate after emulsification.

2. Substances dissolved in a liquid even to a slight degree may greatly affect its surface tension, emulsibility or adhesion.

3. Dissolved substances may exist in the surface layer of a liquid to a greater or less concentration than in the main body of the liquid. This action takes place normally in such manner as to reduce the surface tension of the liquid and hence its surface energy. This concentration may go so far that solid

film is formed on the surface, or to the contrary the surface may show practically no trace of the dissolved substance.

4. When a drop of one liquid is poured gently on the surface of another liquid in some cases it will spread out quickly in a thin layer while if another liquid is used the drop may stay suspended on the surface and have a spherical form. This spreading out is due to the fact that by such action the total surface energy is reduced, that is, the surface tension between the two liquids plus the tension between the top liquid and air is less than that between the original liquid and air. If an increase in surface energy would result from spreading, the drop will remain in spherical form.

5. At a liquid-solid surface there may be such an increased concentration of dissolved material in the surface of the liquid, that by continually passing the liquid over the solid the dissolved substance (solute) will be practically removed from the solution due to adhesion of this liquid surface layer of increased concentration to the solid. This is what happens when oils are passed through filtering substances, as fuller's-earth or charcoal. It should not be claimed, however, that this is due entirely to surface tension phenomena as many other forces may be acting simultaneously and experimental work thus far performed has not been of sufficient definite character as to give an entirely satisfactory explanation.

We have indicated above the usual understanding of the terms, saponification, emulsion and adhesion and incidentally their relationship has become apparent. We shall now discuss these more fully and indicate how these terms are often confused. In causing the formation of emulsions, soaps have been found to be very efficient. Whether this can be explained entirely as a reduction of interfacial surface tension or whether there is a soap film formed between the globules of oil and water which prevents them from coalescing or not, is still a disputed question. Perhaps both conditions prevail along with electrical forces. Nevertheless, soaps, whether added as such or formed in the oil or mixture, do assist emulsification and the apparent cause of the emulsion—saponification—is often confused with the effect—emulsification.

Similarly due either to the soaps, fatty acids or compounds added to an oil to cause it to emulsify, their adhesion is often greatly improved and hence an emulsion is sometimes demanded in order to produce greater adhesion of the oil to a metal or solid surface.

That this is not essential is shown by the fact that compounds can be added to mineral oils that cause them to stick to metal gears even when running under heavy load and with water flowing over them, and yet the lubricants have no soap in them and no evidence of emulsion is apparent. If there is any emulsion at all it is only at the interfacial surface.

Perhaps the best practical examples of emulsion are soluble oils. Soaps are generally used in their preparation, but they are more a convenience than a necessity, as emulsification can be produced by adding correct proportions of such things as alcohol, acetone, and certain fatty acids or oils and many other things.

In the case of greases which are emulsions in which the oil is held, practically speaking, by a net work to prevent it from flowing, soap is found most practical to use, though greases could be formed by mixtures of other substances. The actual structure of greases is not fully understood and in most cases the production of a good or poor grease depends largely upon the skill which the grease maker has attained through experience.

A confusion of terms also often exists among marine engineers in regard to the action of marine engine oil. In order to cause the oil to stick to the guides, piston rods, blocks, etc., a small amount of fatty oil is added to the base of mineral oil. This causes an emulsion with the condensed steam and the amount of water being small the oil becomes pasty, adhering to the metal and resisting the washing action of the water. Many an engineer calls this action saponification, yet there is absolutely no soap used or formed.

Many other examples could be given but it is believed that enough has been said to indicate the distinction between the three terms. It is regretted that due to the incompleteness of the study of the action at interfacial surfaces we cannot give a more comprehensive idea of the cause of such phenomena as we see in liquid-liquid mixtures, or between liquids and solids. Oils and greases are almost universally compounded from empirical data without reference to any theories or general laws and the best products, as a rule, are manufactured by those having the greatest experience and best facilities. A large amount of practical scientific experimentation is greatly desired in order that we may establish workable laws and get away from the rule of thumb methods.

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